COMPARISON OF MANUFACTURED AND MODELED SOLAR CELL

Dávid Strachala, Josef Hylský

Doctoral Degree Programme (1.), FEEC BUT

E-mail: xstrac07@stud.feec.vutbr.cz, xhylsk00@stud.feec.vutbr.cz

Supervised by: Jiří Vaněk

E-mail: vanekji@feec.vutbr.cz

Abstract: The aim of the work is to compare the model of monocrystalline silicon solar cell in PC1D with the real solar cell structure in terms of using a model in manufacture process. Real solar cell was firstly measured and analyzed to determine input parameters for a simulation and then realized in free available PC1D software. Degree of conformity of modeled and real solar cell was in the end established for basic prediction of solar cell parameters before manufacturing process.

Keywords: Model of silicon - monocrystalline solar cell, comparison of modeled and real structure, PC1D, manufacturing process.

1. INTRODUCTION

Due to the availability of software allowing to model the solar cell occurs a question: How much are their outputs applicable in real process? This work deals with the comparison of modeled and real moncocrystalline silicon solar cell related to the use of modeling during the manufacturing process.

Modeling of photovoltaic cells has an indisputable advantage which lies in the possibility of modifying and monitoring the parameters of the solar cell without the necessary financial issue caused by realizing similar operations in the real process. In this way can be identified and measured the most important parameters affecting for example the conversion efficiency of solar cells. For a comparison of the photovoltaic cell model with real solar cells was selected commercially available modeling tool - PC1D.

2. DETERMINATION OF THE REAL SOLAR CELL PARAMETERS

As a reference solar cell was selected one of the five already manufactured monocrystalline silicon solar cells (named SiD17) from the identically process. SiD17 was measured to obtain a parameters needed to create the corresponding model in PC1D.

2.1. Measurements of Solar Cell and Metallization Sizes

For the modeling purposes was firstly determined the dimension of a solar cell. SiD17 is 5” with 125 x 125 mm proportions. Cell thickness was measured to 199 microns. Due to unsatisfactory possibilities of modeling the front metallization in PC1D was also detected thickness of metallization (after sintering paste) shown in Figure 1. and calculated active area of PC1D model reduced by covered area by metallization.

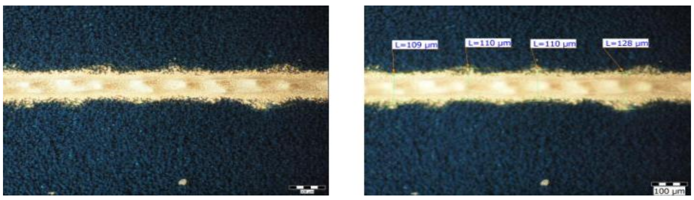

Figure 1: Dimensions of the front metallization

Thickness of front collecting contacts was intended to 0.11 mm with an expected incident radiation shielding of an area of 11.9 square centimeters. Rear cell contact is covered with Al - Ag paste (because of back surface field effect) to a depth of 6 microns.

2.2. BASE MATERIAL, SURFACE TEXTURING AND EMITTER OF SOLAR CELL

Resistivity of *p* - type substrate measured by four-point method was established as $\rho = 1.53\ \Omega \cdot \mathrm{cm}$.

Diffusion of *n* - type emitter with depth of 0.3 microns and peak concentration - $N_p = 3 \cdot 10^{20}\ \mathrm{cm}^{-3}$ (provided by manufacturer) was realized by phosphorus trichloride $POCl_3$ with average measured value of the sheet resistance (after dopant diffusion) $R_{sh} = 47\ \Omega / \square$ (Figure 2.).

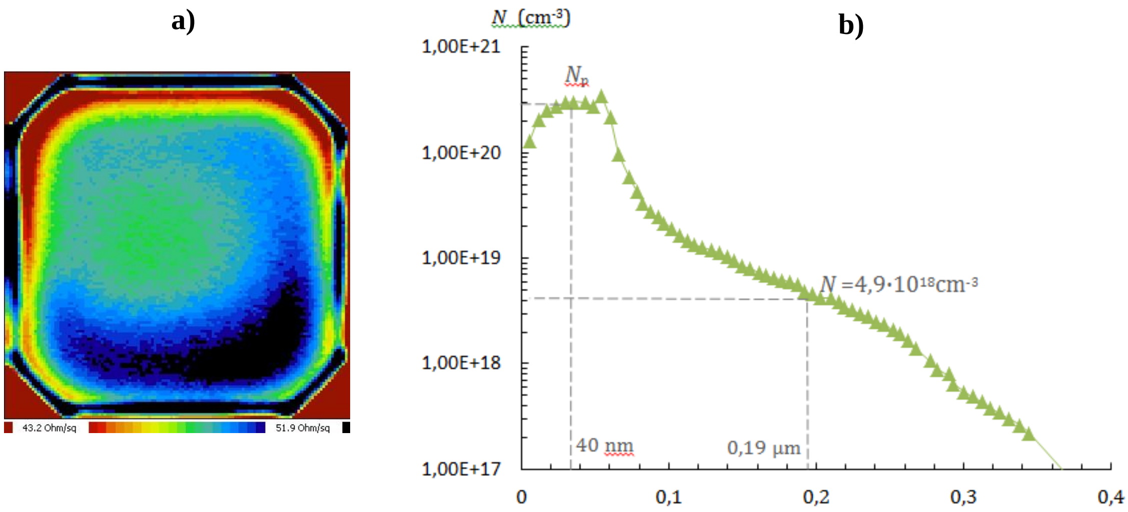

Figure 2: a) Measurement of sheet resistance, b) Dopant concentration

Surface texturing was made in alkaline bath on the both of sides with the average value of removed material 20.3 micron with the 70.5° angle of the front side pyramids.

2.3. PASSIVATION AND ARC LAYER, CARRIER LIFETIME, SERIES AND SHUNT RESISTANCE

Passivation and antireflection layer (ARC) was deposited as non-stoichiometric silicon nitride SiN_x having a thickness of 75 nm (as indicated by the manufacturer).

According the current measurements were then detected dynamic properties of the solar cell from which were determined the bulk lifetime - $\tau_B = 387\ \mu s$.

Measurement of the contact and sheet resistance of the front metallization and the *n* - type emitter were made by TLM - Transmission Line Method with strip guided between two parallel busbar. The value of the measured series resistance was evaluated on $R_S = 1.24\ \Omega \cdot \mathrm{cm}^2$. From the data it was then possible to calculated the value of the shunt resistance $R_{SH} = 77\ \Omega$.

Based on the measurements and the manufacturer provided data were identified the most important parameters used to create a model of the solar cell presented in the following chapter. The list of the most important parameters are shown in Table 1.

Measured or identified parameter [unit]	Value
Area of solar cell without an incident radiation shielding of front metallization [cm^2]	144.35
Thickness of solar cell [µm]	199
Depth of front texturation [µm]	20.3
The apex angle of textures - front side[°]	70.5
ARC + passivation layer - thickness [nm] - refractive index [-]	SiN_x 75 2.19
Reflection at λ = 600 nm [%]	0.534
Series resistance [$\Omega \cdot cm^2$]	1.24
Shunt resistance [Ω]	77
Resistivity of substrates [Ω·cm]	1.53
Peak of dopant concentration - n^+ layer[cm^{-3}]	$3.0 \cdot 10^{20}$
A sheet resistance of emitter [Ω/□]	47
Carrier lifetime [µs]	387

Table 1: Measured and identified pamateres of the real solar cell

3. MODEL OF SOLAR CELL

3.1. PC1D MODEL

Model of solar cell was realized in freely available simulation software - PC1D. PC1D is basic tool for one - dimensional modeling of processes in semiconductor structures. Its interface can be used for understanding and analyzing physics of silicon solar cells with detailed output graphical interface [1].

The structure of measured solar cell SiD17 in PC1D is shown in Fig. 3.

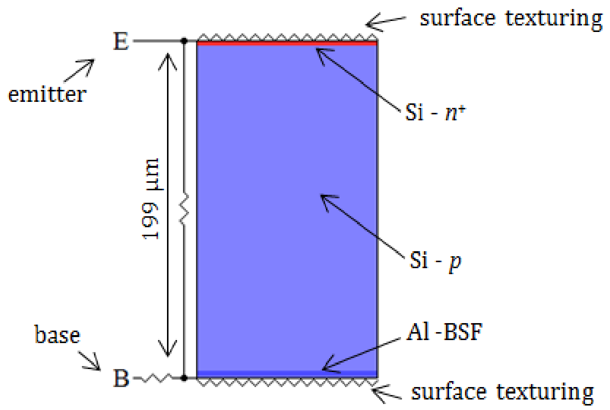

Figure 3: Structue of modeled solar cell SiD17 in PC1D

Model in PC1D was trying to reflect the real parameters of SiD17, but due to the limited possibilities of measurement and parameter settings in PC1D was not possible to create a completely identical structure. Agreement between model and measured structure is illustrated in the next text.

3.2. A COMPARISON OF THE MODELED AND REAL SOLAR CELL - EMITTER

Emitter of SiD17 solar cell is diffused to a depth of 0.35 µm with a peak concentration $N_p = 3 \cdot 10^{20}$ cm^{-3}. Concentration profile of SiD17 including the inactive phosphor glass at a depth of 0.04 µm is shown in Figure 4 a). For a comparison is also shown concentration profile of modeled solar cell in Figure 4 b). In PC1D can be seen that peak concentration is slightly lower with $N_p = 2.8 \cdot 10^{20}$ cm^{-3} at a distance of 0.2 μm and depth of diffused phosphor is at 0.37 μm (erfc function). PC1D is not able to sufficiently reproduced the shape of real concentration profile between 0.02 μm to 0.35 μm which can lead to impreciseness of real and modeled solar cell.

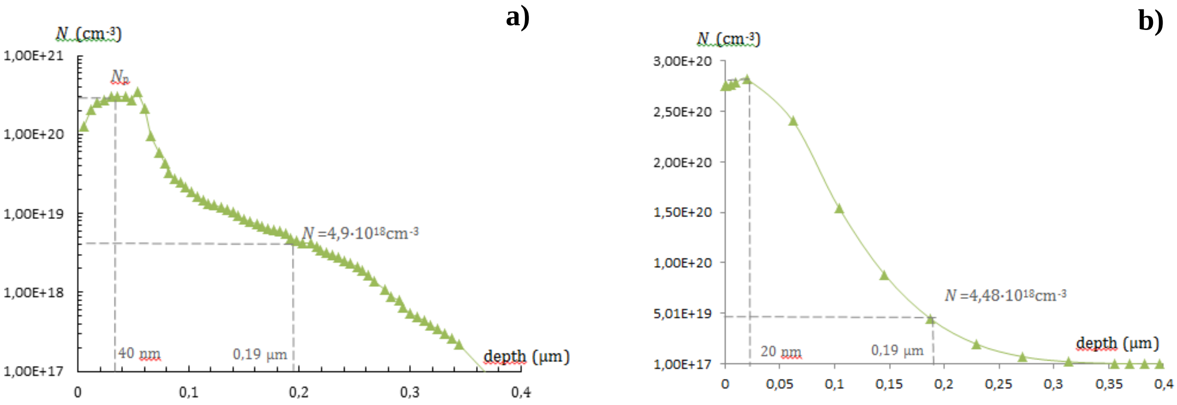

Figure 4: a) Concentration profile of SiD17, b) Concentration profile of PC1D model

3.3. A COMPARISON OF THE MODELED AND REAL SOLAR CELL - EXTERNAL AND INTERNAL QUANTUM EFFICIENCY

In Figure 5 is comparison of external quantum efficiency (EQE) indicating ability to convert incident radiation into electrical energy, and internal quantum efficiency (IQE) which includes the effects of reflection and passage of radiation through the real and modeled solar cell [2].

Area a) of Figure 5 (for internal quantum efficiency) refers about losses caused by surface recombination velocity, b) surface reflection and diffusion length of carriers and c) about recombination of the rear side of the cell [3]. The comparison shows that the losses caused by surface recombination of the front and rear sides are in a simulated model lower than losses in a real cells. Surface reflectance is on the other hand more acceptable for a real structure, probably due to inaccurate modeling of optical reflection in PC1D.

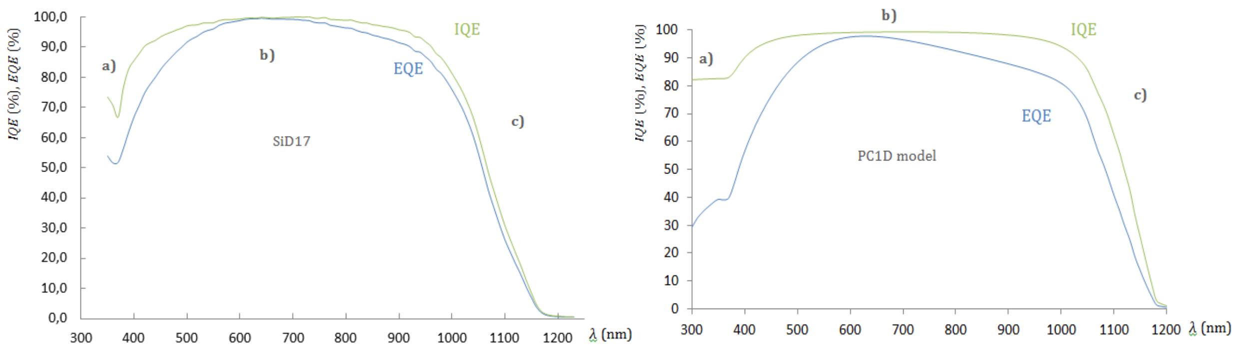

Figure 5: a) Concentration profile of SiD17, b) concentration profile of PC1D model

4. THE RESULT OF COMPARISON

Comparison of the major parameters (short-circuit current, maximum output power, open circuit voltage, fill factor and conversion efficiency) of modeled and real solar cell based on simulations in PC1D and actual values for SiD17 is summarized in Table 2. Significant differences are especially in short-circuit current parameter, which is in SiD17 at about 200 mA less than in the PC1D model. This may be caused due to imperfect modeling of metallization influence (series resistance), lower front surface recombination velocity of the modeled solar cell and inconsistent assessment of optical losses in PC1D. Consensus of model and SiD17 occurred in open circuit voltage parameter where the difference is only 3mV. In terms of conversion efficiency is achieved higher values in the modeled one - the difference is 0.45%. The reasons are mainly in the effects of manufacturing process - pollution of substrate, cell degradation etc., which cannot be modeled in PC1D.

Parameter	Model	SiD17
I_{SC} [A]	5.481	5.298
U_{OC} [V]	0.622	0.625
FF [%]	81.6	79.56
η [%]	18.45	18

Table 2: Parameters of model and real solar cell

5. CONCLUSION

The aim of the work is in possibility of using freely available simulation software - in this case PC1D for modeling photovoltaic cells in terms of conformity of the model with the real structure. According a measured and received data from manufacture process was created a model of SiD17 (real solar cell) which had different value of short - circuit current (0.2 A higher), conversion efficiency (0.45 % higher), fill factor (2 % higher) and similar value of open-circuit voltage (0.003 V lower).

Due to the one-dimensional modeling in PC1D, inability to capture all the effects on the solar cell during its manufacture together with limited opportunities to identify all parameters of the real solar cell is the degree of conformity of the model and the SiD17 sufficient. Modeling of solar cell in PC1D can be used to preliminary prediction of the resulting parameters of solar silicon monocrystalline structure before a manufacturing process begin.

ACKNOWLEDGEMENT

This research work has been carried out in the Centre for Research and Utilization of Renewable Energy (CVVOZE). Authors gratefully acknowledge financial support from the Ministry of Education, Youth and Sports of the Czech Republic under NPU I programme (project No. LO1210) and BUT specific research programme (project No. FEKT-S-14-2293).

REFERENCES

[1] STRACHALA, D. *Modifikace struktury křemíkových solárních článků.* Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, 2014. 72 s. Vedoucí diplomové práce Ing. Ondřej Hégr, Ph.D.

[2] MOJROVÁ, B. *Využití měřicí metody SPM v technologii výroby krystalických solárních článků.* Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, 2013. 61 s. Vedoucí diplomové práce Ing. Ondřej Hégr, Ph.D.

[3] MEIER, D., E. GOOD, R. GARCIA, B. BINGHAM, S. YAMANAKA, V. CHANDRASEKARAN, C. BUCHER, C16 COMMITTEE, C16 COMMITTEE, C16 COMMITTEE a C16 COMMITTEE. Determining Components of Series Resistance from Measurements on a Finished Cell. 2006 IEEE 4th World Conference on Photovoltaic Energy Conference. 2001. DOI: http://dx.doi.org/10.1520/c1155.